Composite Safety & Certification Initiatives

Presented at: Fort Worth DER Seminar

By: Larry Ilcewicz,
CS&TA, Composites

Date: May 25, 2006

Agenda

- Background and Timelines
  - Review progress through 2005
  - Ongoing efforts and future plans
- Technical Status
  - Damage tolerance
  - Service history
  - Bonded structure
  - Maintenance training
- Mil-Handbook-17
- Summary

Ongoing Composite Safety & Certification Initiatives*

Objectives

1) Work with industry, other government agencies, and academia to ensure safe and efficient deployment of composite technologies used in existing and future aircraft

2) Update policies, advisory circulars, training, and detailed background used to support standardized composite engineering practices

** Efforts started in 1999 to address issues associated with increasing composite applications*

Technical Thrust Areas

Advancements depend on close integration between areas

Material Control, Standardization and Shared Databases

Damage Tolerance and Maintenance Practices
- Critical defects (impact & mfg.)
- Bonded structure & repair issues
- Fatigue & damage considerations
- Life assessment (tests & analyses)
- Accelerated testing
- NDI damage metrics/service POD
- Equivalent levels of safety
- Training standards

Structural Substantiation
- Advances in analysis & test building blocks
- Statistical significance
- Environmental effects
- Manufacturing integration

FAA and NASA R&D is currently active in most of these areas

NASA

Bonded Joint Processing Issues

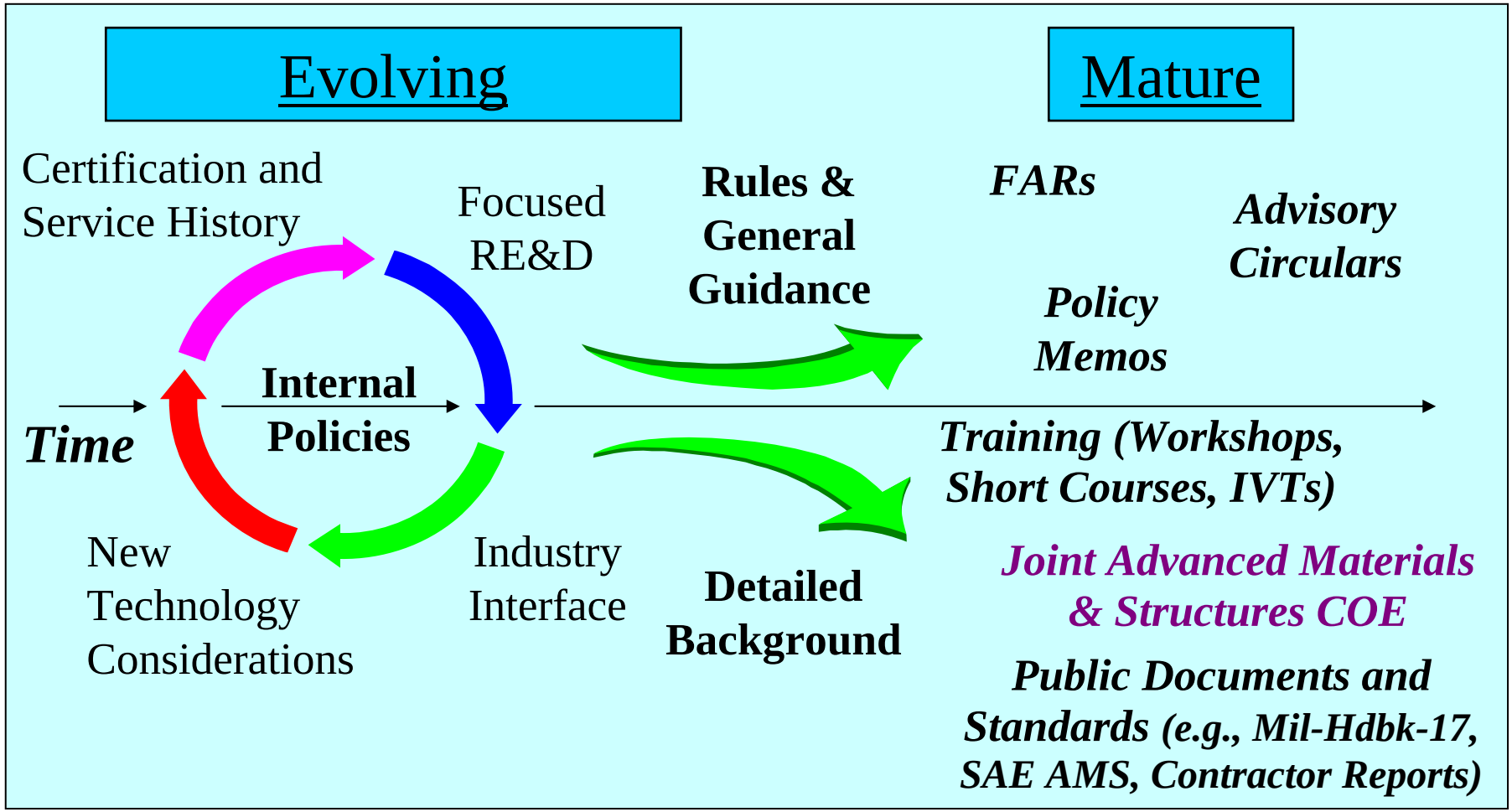
Advanced Material Forms and Processes

Flammability & Crashworthiness

Support from cabin safety research groups

Significant progress, which has relevance to all aircraft products, has been gained to date

FAA Approach to Composite Safety and Certification Initiatives



FAA Joint Advanced Materials and Structures (JAMS) Centers of Excellence

New FAA JAMS Centers of Excellence to provide research and training in support of expanding composite applications

CECAM
center of excellence for composites and advanced materials

FAA Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Wichita State University

Northwestern University
Purdue University
Tuskegee University
University of California at Los Angeles
University of Delaware

University of Washington

Edmonds Community College
Oregon State University
Washington State University

FAA Composite Team Members

Represented Group	Team Member Name	FAA Organization Number & Routing
FAA Tech. Center	Curtis Davies	AAR-450 (FAA Technical Center)
	Peter Shyprykevich	AAR-450 (FAA Technical Center)
International	John Masters	AEU-100 (Brussels Aircraft Certification Staff)
Directorates	Lester Cheng	ACE-111 (Small Airplane Directorate)
	Mark James	ACE-111 (Small Airplane Directorate)
	Charles Harrison	ASW-110 (Rotorcraft Directorate)
	Richard Yarges	ANM-115 (Transport Airplane Directorate)
	Jay Turnberg	ANE-110 (Engine & Propeller Directorate)
Flight Standards	Rusty Jones	AFS 309 (Aircraft Maintenance Division)
ACOs, MIDOs, & CMOs	Roger Caldwell	ANM-100D (Denver ACO)
	Mark Freisthler	ANM-120S (Seattle ACO)
	Ed Garino	ACE-117A (Atlanta ACO)
	Fred Guerin	ANM-120L (Los Angeles ACO)
	Angie Kostopoulos	ACE-116C (Chicago ACO)
	David Ostrodka	ACE-118W (Wichita ACO)
	Richard Noll	ANE-150 (Boston ACO)
	John Harding	ANM-108B (Seattle CMO)
	David Swartz	ACE-115N (Anchorage ACO)
CS&TA	Larry Ilcewicz	ANM-115N (CS&TA, Composites)

Not intended to be inclusive. More team members are encouraged and currently needed.

CSTA and STS Advisors:
Al Broz, Robert Eastin, John Howford, Terry Khaled, Steve Soltis, Dave Walen, Chip Queitzsch

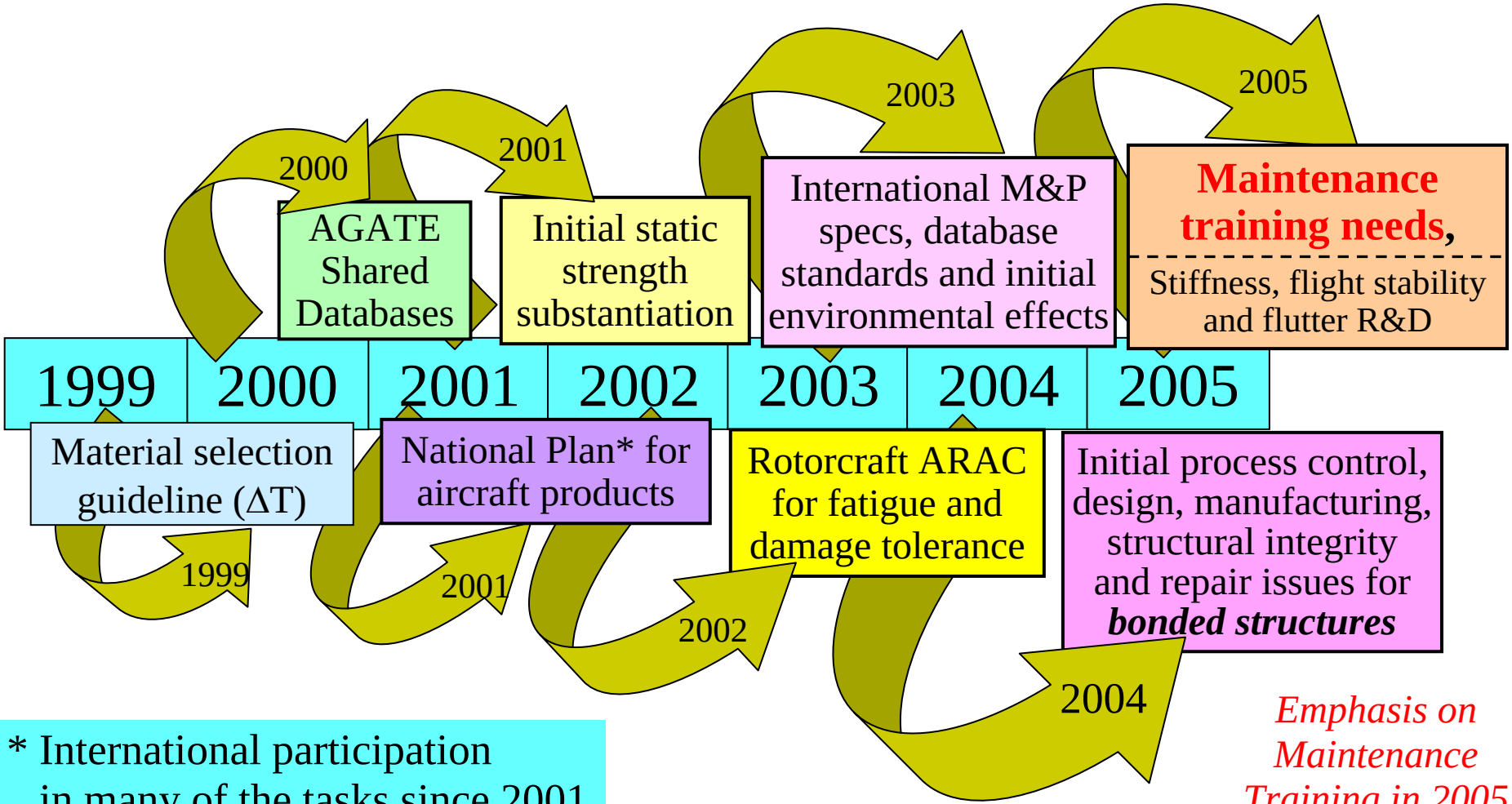
Important Teammates

- NASA has been a leader for composite applications
  - Significant research support since 1970/1980s
  - AA587, A300-600 accident investigation
  - NCAMP support to material standardization
- Partnerships with industry have been essential, e.g., Mil-17, SAE P-17, CACRC, ASTM, SAMPE, AGATE, SATS, RITA, SAS/IAB/AACE

Training
Databases
Standardization
Engineering guidelines

- DOD and DARPA research
- EASA and other foreign research/standardization

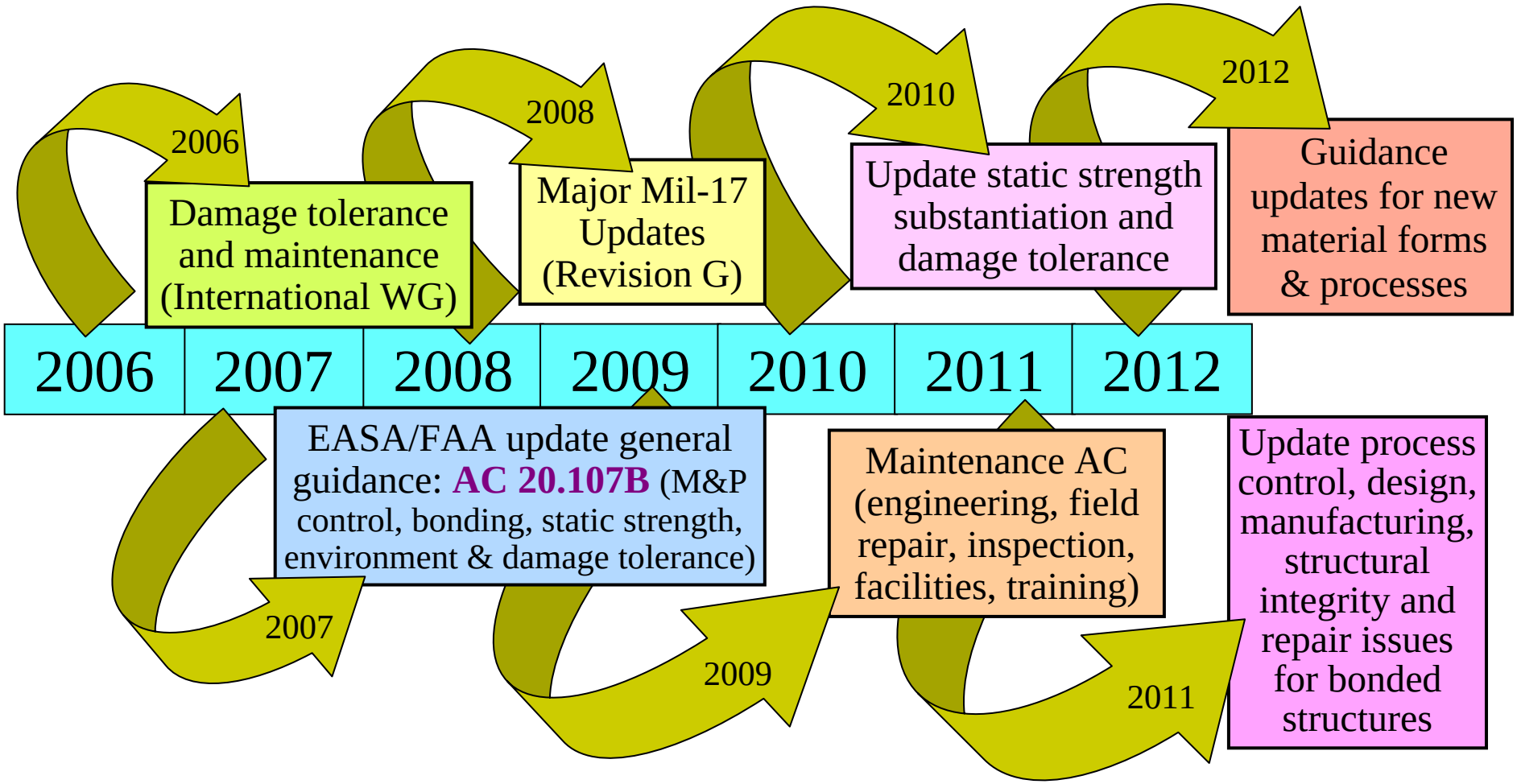
Milestones for Composite Safety and Certification Policy, Guidance & Training



* International participation in many of the tasks since 2001

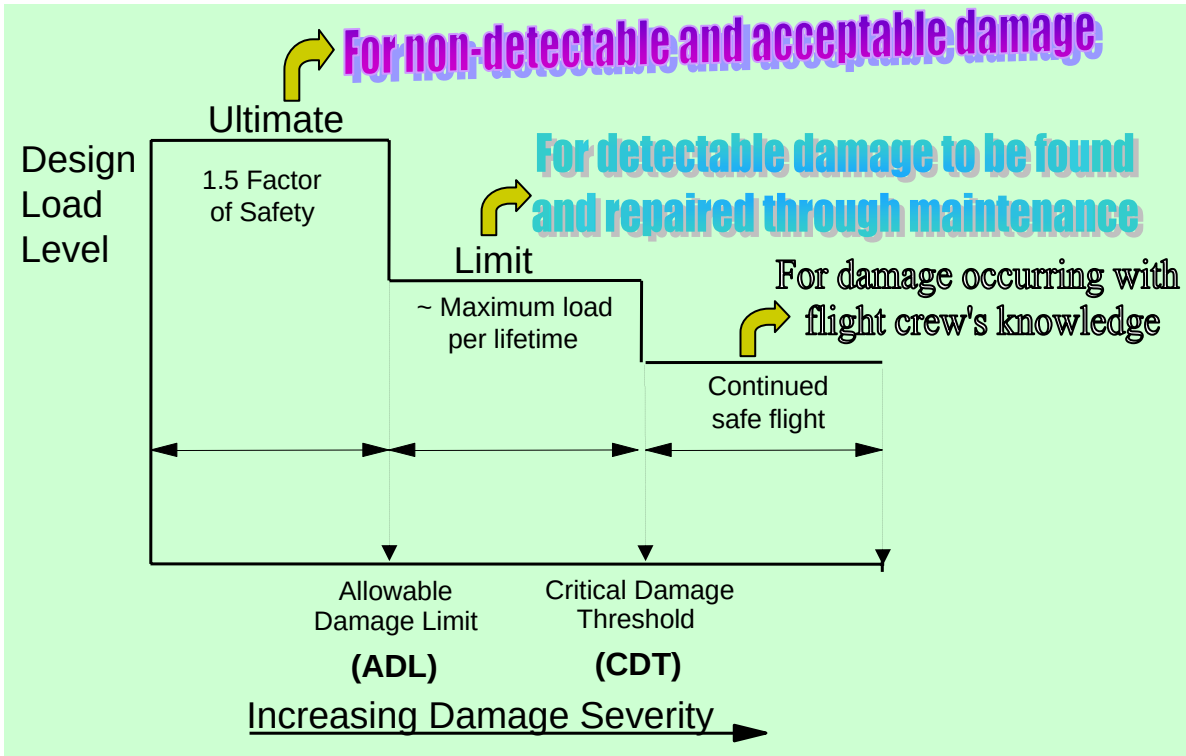
Emphasis on Maintenance Training in 2005

Milestones for Composite Safety and Certification Policy, Guidance & Training



General Structural Design Load and Damage Considerations

- *Lost Ultimate load capability should be rare* (with safety covered by damage tolerance & practical maintenance procedures)
- Fatigue evaluations to identify damage scenarios and demo life
- Damage tolerance evaluations to show sufficient residual strength for damage threats (accidental, fatigue, environmental and discrete source)
- Both support maintenance (e.g., inspection intervals and replacement times)



Critical Composite Damage Threats

- Non-detectable damage (e.g., barely visible impact damage) applied with the Ultimate load requirement
- Accidental service damage that can be detected with selected maintenance inspection procedures
  - Ranging from detectable to clearly visible to obvious
  - Complex damage states from different sources
  - Repeated loads (inspection intervals & Limit load requirement)
- Anomalous service incidents (e.g., severe overloads and service vehicle collisions) that should be reported
- Manufacturing flaws (e.g., local weak bonds) that are not initially detected but become detectable in service
- Discrete source damage scenarios

Key Composite Behavior for Fatigue and Damage Tolerance Assessment

- Relatively flat SN curves & large scatter
  - Leading to “no growth” *normal fatigue* demonstrations
  - Load enhancement factors needed to show reliability
  - Growth options have been applied conservatively
    To show high loads needed for growth
    Past structure evaluated with a growth approach typically don’t have a residual strength issue
- Sensitivity to impact and significant manufacturing defects
  - Complex damage that trigger interactions between interlaminar and translaminar failure modes must be evaluated for *anomalous fatigue*
    Growth options may be viable for some mixed mode, delamination
  - Compression and shear residual strength are affected by damage
    Critical for many structures
  - Similar tensile residual strength behavior to metals
    Sharp cracks and blunt notches yield similar results for composites

Additional Thoughts on Bonding

- A well-qualified structural bonding process and strict material & process controls are paramount
  Fatigue and damage tolerance methods can not cover for an "unacceptable bonding process"
  Reason 1: the degradation of "weak bonds" is generally not predictable or repeatable in mechanical tests
  Reason 2: bad chemistry, real time and environmental effects dominate the degradation process
  Reason 3: large area debonding is unacceptable for a large number of structural details (i.e., degradation is not "rare")
- Fatigue & damage tolerance methods are useful for structure using a qualified bonding process that is under control
  Reason 1: to cover *rare, local debonding* that occurs for good processes
  Reason 2: to provide fail-safety & coverage for accidental damage

Boeing/Airbus/FAA/EASA WG for Damage Tolerance and Maintenance

Objectives

1. Agree on critical technical issues and areas of safety concern for damage tolerance & maintenance of composite structure on transport aircraft.
2. Identify key similarities and differences in methods used to substantiate damage capability for transport aircraft composite structures.
3. Identify the key elements necessary to substantiate maintenance inspection and repair procedures for composite aircraft structures.
4. Identify related content needed to update appropriate approved source (OEM) documentation (MPD, SRM, etc.) focused on field safety issues.
5. Identify related content needed to update the Mil-17 Damage Tolerance and Supportability chapters and the FAA composites maintenance training standards, as appropriate.
6. Identify areas for safety-related standardization of composite damage tolerance & maintenance and related research needed in the future.

Boeing/Airbus/FAA/EASA WG for Damage Tolerance and Maintenance

Justification: expanding transport applications justify a need for communication on composite damage tolerance and maintenance between OEM and regulatory bodies

- Lack of trained resources with practical experiences
- Cost advantages from more common and efficient procedures

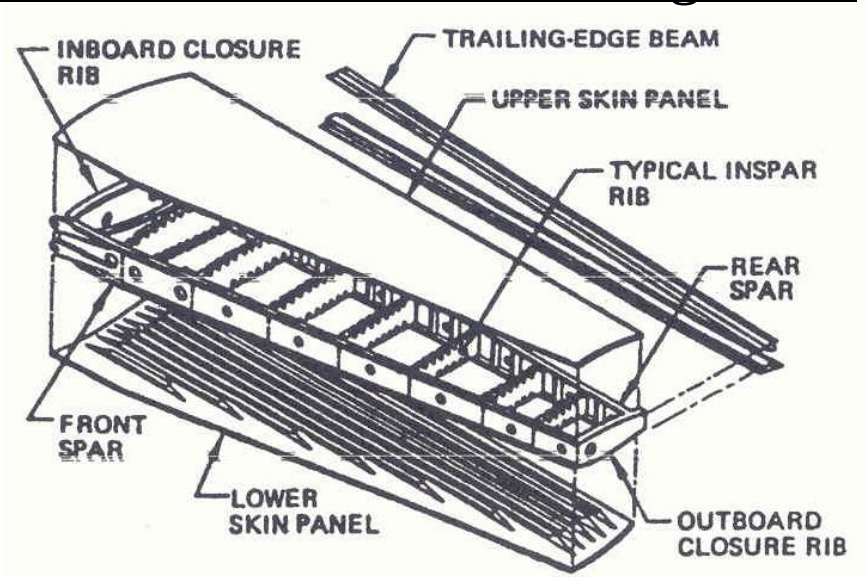
Approach

- Bring key members of the OEM and regulatory bodies together for initial assessment of objectives 1) thru 3) and define deliverables *[meetings 1 & 2]*
- Review progress with key members of the user community (airlines, MRO, AEG and AFS) *[meeting 3 and related 2006 & 2007 workshops]*
- Prioritize WG deliverables and finalize a working plan *[meetings 1 & 2]*
- Use existing standards organizations (Mil-17, SAE CACRC) and educational institutions (FAA JAMS COE) to publish standards and provide training

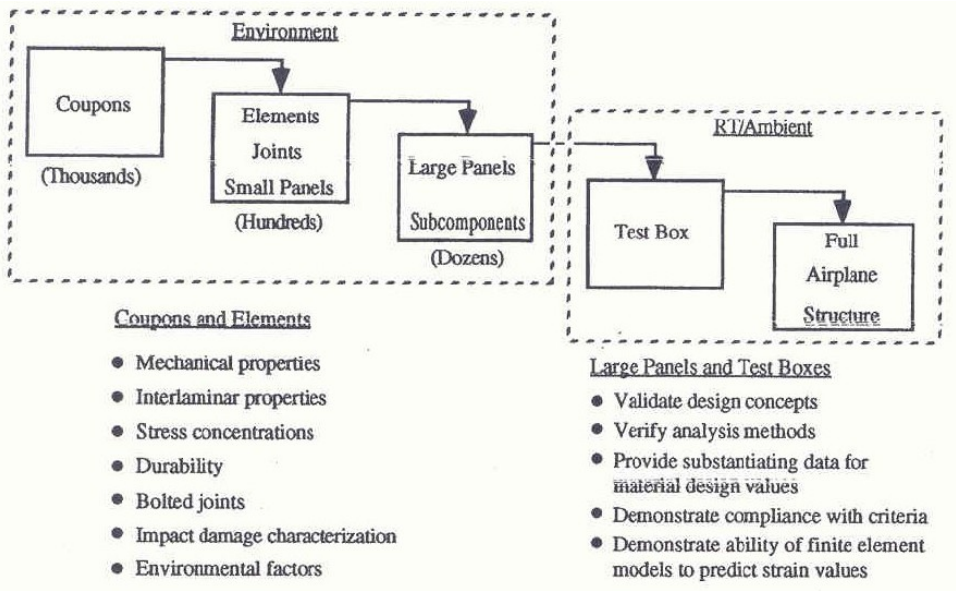
Boeing 737 Composite Horizontal Development and Certification

Developed and certified under NASA Aircraft Energy Efficiency, ACEE, program (1977-1982)

NASA ACEE 737 Horizontal Stabilizer Structural Arrangement



Building Block Approach



Taken from: ”Structural Teardown Inspection of an Advanced Composite Stabilizer for Boeing 737 Aircraft," D. Hoffman, J. Kollgaard and Matthew Miller, 8th Joint FAA/DoD/NASA Aging Aircraft Conference, January, 2005.

Service Experiences for Boeing 737 Composite Horizontal Stabilizer

- Five shipsets entered service in 1984
- Structural inspection program that included detailed visual inspection, with some pulse-echo ultrasound in specific areas to collect fleet data
- Four significant service-induced damage events to main torque box structure as of 2001 technical paper:
  - (1+2) De-icer impact damage to upper surface skins
  - (3) Fan blade penetration of lower surface skin
  - (4) Severe impact damage to front spar web and upper & lower chord radii

Taken from: ”Composite Empennage Primary Structure Service Experience," G. Mabson, A. Fawcett and G. Oakes, CANCOM Conference, Montreal, Canada, August 2001.

Boeing 737 Composite Horizontal Stabilizer Service History

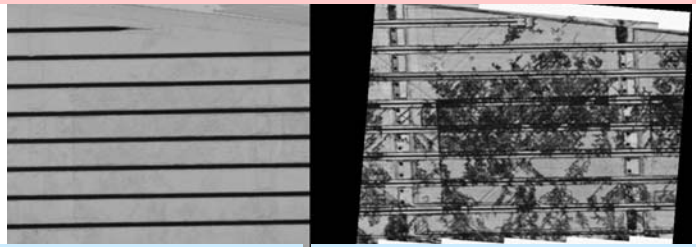
Shipset	Production Line Number	Entry into Service	Status as of October 31, 2004
1	1003	2 May 1984	In service (58000 hours, 43000 flights)
2	1012	21 March 1984	In service (58000 hours, 44000 flights)
3	1025	11 May 1984	Damaged beyond repair 1990; partial teardown of stabilizers completed 1991 (17300 hours, 19300 flights).
4	1036	17 July 1984	Stabilizers removed from service 2002 (approx. 39000 hours, 55000 flights); partial teardown of right hand unit
5	1042	14 August 1984	Stabilizers removed from service 2002 (approx. 52000 hours, 48000 flights); teardown of left hand unit reported here; right hand unit donated to the FAA Tech Center (FAATC) for their teardown activities being conducted at the National Institute for Aviation Research (NIAR) at Wichita State University

Taken from: ”Structural Teardown Inspection of an Advanced Composite Stabilizer for Boeing 737 Aircraft," D. Hoffman, J. Kollgaard and Matthew Miller, 8th Joint FAA/DoD/NASA Aging Aircraft Conference, January, 2005.

B737 Horizontal Stabilizer Teardown Inspection

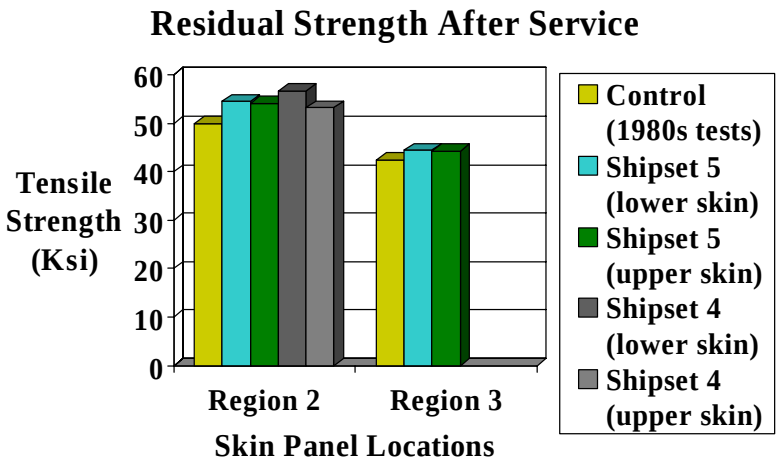
- Inspections found little deterioration due to wear, fatigue, or environmental factors
- Production NDI results indicated today's factory "standard" advanced beyond that of early 1980s
  - High levels of porosity are evident in much of the composite structure
- Mechanical tests of coupons and elements cut from B737 stabilizers had residual strength equivalent to those obtained more than 20 years ago

Factory Ultrasonic Scans of Skin Panels



1980's Vintage
1 MHz ATTU

Today's 3.5 MHz
Thin Film Pulse Echo



Progress and Plans in the Bonded Structures Initiatives 2000 to 2005

Sept. 2005 Release FAA policy for Bonded Joints & Structures

Oct. to Dec. 2004 Draft FAA policy for Bonded Structures, FAA workshop in Europe, update reports

July to Sept. 2004 Draft FAA TC Bonded Structures Report to benchmark industry and outline policy

June 2004 FAA workshop to review survey and collect insights from bonding experts at Mil-17 mtg.

Feb. to May, 2004 Setup AACE research grant to survey the industry, develop 2004 workshop agenda and invite speakers

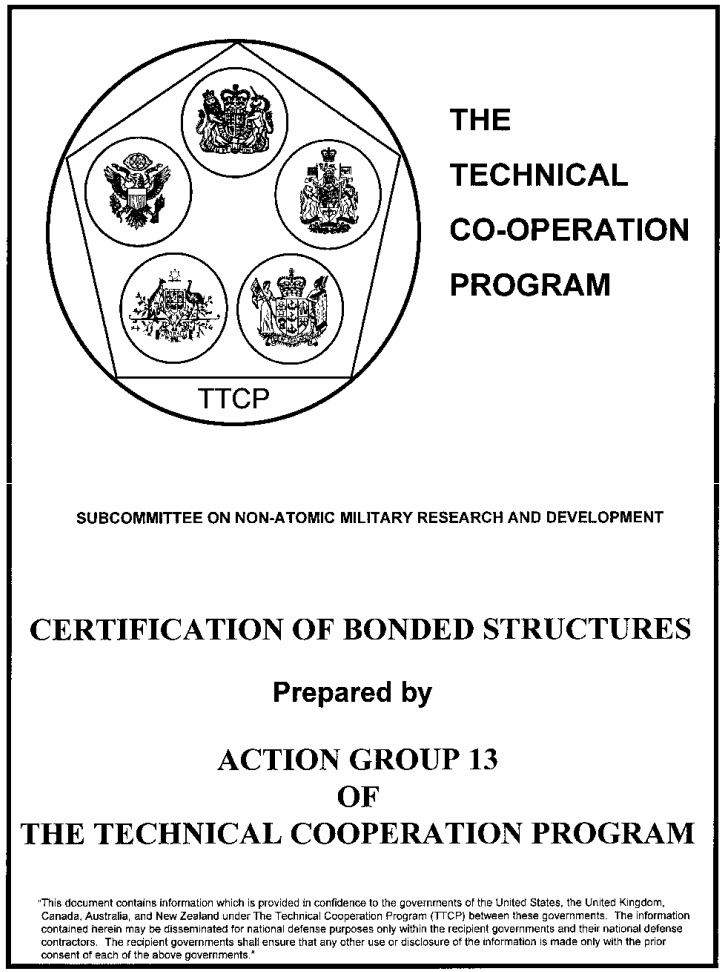
May 2003 to Jan. 2004 Identify experts to support work, develop detailed plans, and collect initial inputs at 2003 M&P workshop

Feb. 2001 TTCP document on “Certification of Bonded Structures”

2000 to 2003 FAA research per the *“Don Oplinger Plan”*

Progress for Bonded Structures
Action Groups for Detailed Documentation

- Some guidance for bonded structures, which comes from military and commercial aircraft experiences, are documented in a TTCP report
  - Chairman: Jack Lincoln, WPAFB
  - Composite and metal bonding
  - Starting point for current effort
- Mil-17 Debond & Delamination Task Group since 2000
  - T.K. O'Brien, K. Kedward and Hyonny Kim are Co-chairman


THE TECHNICAL CO-OPERATION PROGRAM

TTCP

SUBCOMMITTEE ON NON-ATOMIC MILITARY RESEARCH AND DEVELOPMENT

CERTIFICATION OF BONDED STRUCTURES

Prepared by

ACTION GROUP 13
OF
THE TECHNICAL COOPERATION PROGRAM

This document contains information which is provided in confidence to the governments of the United States, the United Kingdom, Canada, Australia, and New Zealand under The Technical Cooperation Program (TTCP) between these governments. The information contained herein may be disseminated for national defense purposes only within the recipient governments and their national defense contractors. The recipient governments shall ensure that any other use or disclosure of the information is made only with the prior consent of each of the above governments.

2004 Bonded Structures Initiative
Justification and Purpose

- Bonding applications for the manufacture & repair of aircraft structures exist throughout the industry
  - New applications are expanding faster than the qualified workforce, making documentation and training a priority
- Technical issues are complex and cross-functional, requiring extensive teamwork for successful applications
  - Known production and service bonding problems highlight a need to properly document the associated technical issues

Collectively, the industry and regulatory agencies should be able to combine our bonding experiences and technical insights to the mutual benefits of improved safety and efficiency in development & certification

2004 Bonded Structure Initiative

Objectives for 6/04 Workshop & Follow-on Report(s)

Primary objective

Collect & document technical details that need to be addressed for bonded structures, including critical safety issues and certification considerations

Secondary objectives

1) *Give examples of proven engineering practices*
2) *Identify needs for engineering guidelines, shared databases and standard tests & specs*
3) *Provide directions for research and development*

Presentations at http://www.niar.wichita.edu/faa/

Technical Scope of the Bonded Structures Workshop

Material & Process Qualification and Control

Bonding applications where at least one side of the joint is metal or pre-cured composite

Manufacturing Implementation and Experience

Regulatory Considerations

- Proof of structure: static strength
- Fatigue and damage tolerance
- Design and construction
- Materials and workmanship
- Durability
- Material strength properties & design values
- Production quality control
- Instructions for continued airworthiness
- Maintenance and repair

General aviation, rotorcraft and transport aircraft

Design Development and Structural Substantiation

Commercial and military applications were reviewed

Repair Implementation and Experience

Small Airplane Directorate Policy for Bonded Joints & Structures

U.S. Department of Transportation

Federal Aviation Administration

Memorandum

Subject: **INFORMATION**: Bonded Joints and Structures - Technical Issues and Certification Considerations; PS-ACE100-2005-10038

Date:

Posted to Federal Registrar for public comments in April, 2005

Released to Federal Registrar in September, 2005

From: Acting Manager, Small Airplane Directorate, ACE-100

Reply to Attn. of: Lester Cheng; 316-946-4111

To: See Distribution

Purpose

1. To review the critical safety/technical issues
2. To highlight some of the successful engineering practices employed in the industry
3. To present regulatory requirements and certification considerations pertinent to bonded structures

Policy for Bonded Joints & Structures Section 3: Technical Issues

- Material & process qualification and control
  - Needed for materials to be bonded and the bonding process
- Design development and structural substantiation
  - Building block approach to test and analysis correlation has benefits for manufacturing and maintenance actions
- Manufacturing and repair implementation
  - A “process control mentality” is essential to successful bonding (overall quality management)
- Service experiences
  - Bond adhesion failures found in service justify *immediate* directed inspections and repair

Policy for Bonded Joints & Structures Section 4: Certification Considerations

- Design and construction
  - Bond design & process details qualified by tests
  - Specifications to control qualified materials & bond processes
- Structural substantiation
  - Large scale tests needed for final validation of static strength, fatigue and damage tolerance
- Production and repair
  - Training and quality management of facilities, tooling & processes
- Continued airworthiness
  - Inspection, disposition and repair must address field issues
- Other elements
  - Communication between design, production and service groups

Future FAA Plans for Bonded Structures Initiatives

- Draft FAA Technical Center Reports (2005 & 2006)

"Assessment of Industry Practices for Aircraft Bonded Joints and Structures" 2005 FAA research report is available at http://actlibrary.tc.faa.gov/

  - Primary content: information collected on bonding issues critical to safety & certification (before/during/after workshops)
  - Secondary content: Give examples of proven engineering practice, future R&D directions and standards support needs
  - Publicly release reports for purposes of training, coordination and standardization
- Continue to work on composite safety and certification initiatives related to bonded structures
  - Future advisory circular and updates to policy
  - Establish training through JAMS COE

2004 - 2006 Composite Maintenance Initiatives

- FAA research at JAMS COE
  - Continued evaluation of existing procedures with CACRC
  - Evaluate training needs and establish a standard intro course
- Series of workshops to bring regulators and industry together on technical issues
  - FAA/NRC Workshop in Wash. DC (May 18 & 19, 2004) *Executive review of systematic, repair, NDI & training issues*
  - 2004 Kickoff for FAA research to evaluate training needs
  - 2005 and 2006 FAA Workshops to review progress in establishing training needs

Training Initiative: *Critical Composite Maintenance & Repair Issues*

- Practical, introductory-level course for engineers, technicians and inspectors is under development
  - FAA/Edmonds C.C. Cooperative Agreement (2004-2006)
  - Short course (5–7 days), incl. labs, worth 3-5 credits
  - Current efforts include web-based, distance learning
- Industry & government experts recruited to support the development of training *standards*
  - 2004 Seattle workshop defined terminal course objectives (TCO)
  - 2005 Chicago workshop used to review draft modules that will be released with the TCO as *industry standards*
  - **Boeing/Airbus/EASA WG review – recommend updates**
  - Initial course scheduled to be completed in 2006
  - FAA report with *industry standard modules* released in 2006

Primary Deliverables

- Terminal Course Objectives (TCO) + Course Description Abstract
- Modules *(industry standards)* Safety Messages
- Standard Student Assessments

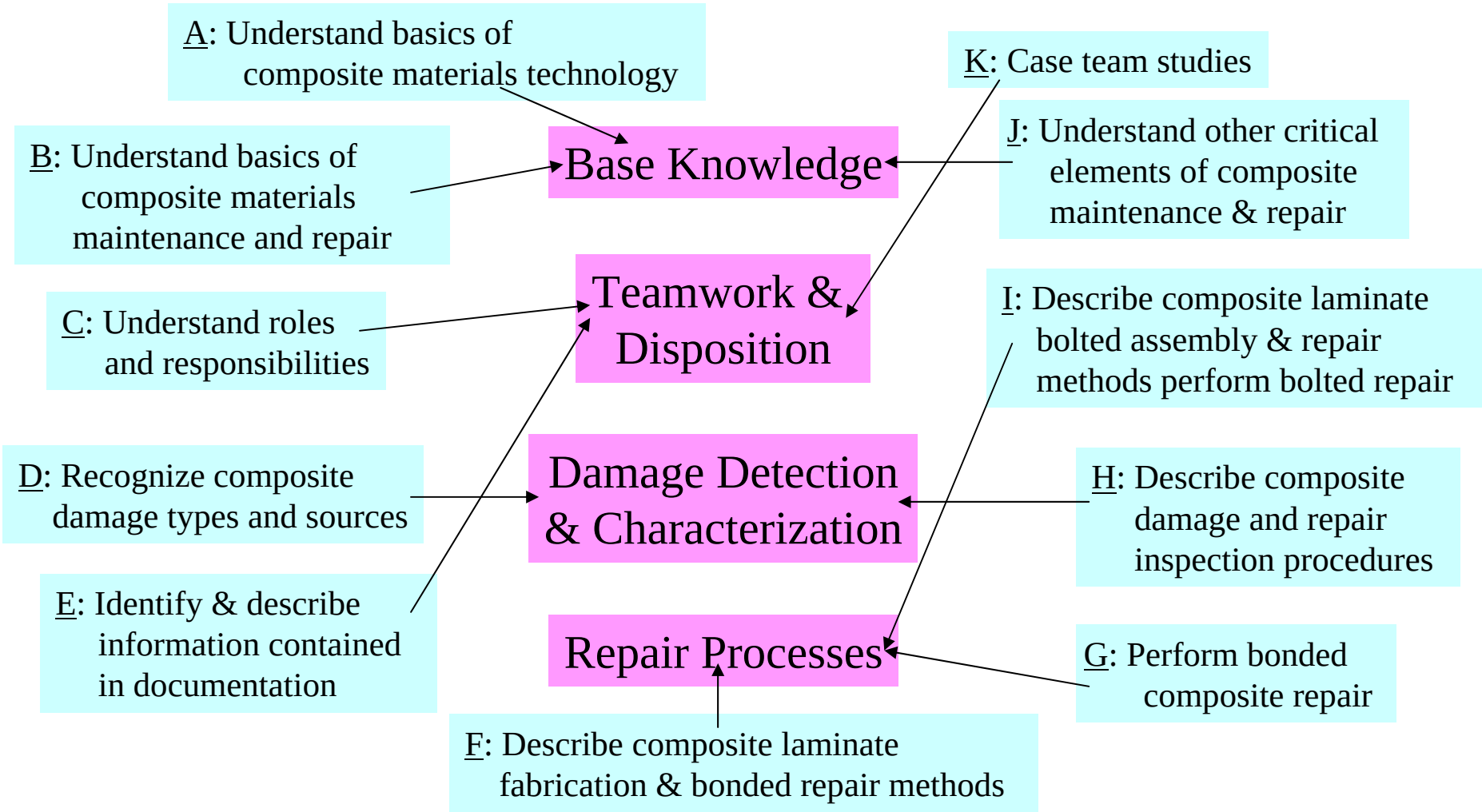
Coordinated Release Through SAE CACRC and FAA Technical Center

- Testimonials (volunteers support)
- Storyboard of a typical course outline

Edmonds C.C. Website

- FAA guidelines (precursor to policy) on training needs: ***Critical Composite Maintenance & Repair Issues***

TCO Broken into Key Subjects for Purpose of Overview



Base Knowledge

- Prerequisite modules (to be provided as self study)
  Module A: *Understand basics of composite materials*
  Module B: *Understand basics of composite maintenance and repair*
  Module J: *Realize other critical elements of composite maintenance and repair*
- Developed by Keith Armstrong
  - Basic composite knowledge that will be useful for engineers, inspectors, technicians and others that will take the course
- Many elements covered in Module J are also intended to make students aware of some important areas that will not be covered by the main course

Teamwork and Disposition

- Unique modules with critical safety messages
  Module C: *Understand roles and responsibilities*
  Module E: *Identify & describe info contained in documentation*
  Module K: *Case team studies [Lab #6]*
- Successful maintenance & repair relies on teamwork
  - Engineers, inspectors & technicians have diverse training needs and acquired skills
  - Good communication between OEM and users
- Approved maintenance practices and repair procedures are developed & substantiated to meet requirements
  - Specific product design, process and database dependence
  - Limits and constraints of approved source documentation

Damage Detection & Characterization

- Essential modules for detecting and solving a problem
  Module D: *Recognize composite damage types and sources*
  Module H: *Describe composite damage and repair inspection procedures*
- Working outside the limits of approved documentation
  - Difficult to substantiate repair of all possible environmental and accidental damage cases in initial type certification
  - Standard designs, analyses & shared databases don't exist to support the substantiation of composite field repairs
- Some damage scenarios require special inspections
  - Communication between operations, maintenance and OEM personnel for anomalous damaging events

Repair Processes

- Modules needed to realize critical issues in composite repair processes and quality control procedures

  Module F: *Describe composite laminate fabrication and bonded repair methods*

  Module G: *Perform bonded composite repair*

  Module I: *Describe composite laminate bolted assembly & repair methods and perform/inspect bolted repair*

- Hands-on labs, videos and testimonials help gain an appreciation for process-related safety messages
- Design and process detail differences are likely in advanced, product-specific, “how-to” training

Importance of Mil-Handbook-17 and Other Composite Standards Efforts

- Brings composite industry together with regulatory agencies and other government groups to determine the “best engineering practices”
- Consensus-driven/user acceptance helps ensure reliable engineering databases, methods and procedures for a workforce that is expanding with new applications

- Provides a forum on topical engineering concerns and new technology needs

Long-Term Plans for Mil-17

Justification: shared databases and engineering guidelines are needed for expanding applications

- Long-term plans for Mil-17 are integrated with FAA CS&CI
- Continuously seek inputs for Mil-17 directions and priorities
  - Sponsors
  - User review & advisory groups
  - Executive committee
  - Partner organizations
- Some commercialization to support Mil-17 organization
- Highlights of Revision G updates
  - Databases coupled with M&P specs (electronic data for members)
  - New volume on sandwich structures (major updates to Mil-23)
  - Boeing/Airbus/EASA/FAA WG updates to damage tolerance and supportability chapters
  - New Chapters for certification, design, analysis, crashworthiness and structural safety
  - Introduction and major reorganization of Volume 3

Mil-17 Forum Subjects

- FAA bonded joints workshop
  - Seattle, June 16-18, 2004 *(150 participants from around world)*
- Database standards and material & process specs
  - Progress in NCAMP, SAE P-17 and Mil-17 efforts
- Advanced building block analysis and tests
  - U.S./International test standards *(ASTM)*
- Updates from FAA damage tolerance and repair research *(Joint efforts including WSU, Boeing, EASA and CACRC)*
- New transport, rotorcraft and small airplane projects
- AA587 Accident Investigation (February, 2005)
- FAA composite damage tolerance & maintenance workshop
  - Chicago, July 19-21, 2006

Long-term Plans for Composite Safety and Certification Initiatives

A multi-year plan has been developed and implemented

- Initially based on recent general aviation applications
- Input for rotorcraft and transport aircraft since 2001
- Will be continuously reviewed and updated in public forum (e.g., Mil-17, national conferences, “town meetings” and FAA seminars & workshops – ***your input is requested***)
- Continuously integrated with FAA strategic & business plans
- Research supports future policy, guidance & training
- Continued support by NASA, other government agencies, and industry are critical to future efforts
- Focus on maintenance in 2006 & damage tolerance in 2007

Progress in Composite Safety and Certification Initiatives

Milestones achieved to date

- FAA policy/training for base material qualification & equivalency testing for shared databases (update 2003)*
- Policy/training for static strength substantiation based on small airplane certification experiences (2001)
- New rule and AC for damage tolerance & fatigue evaluation of composite rotorcraft structure have been drafted (2002)
- New AC for material procurement & process specs (2003)*
- Revision F to Mil-Handbook-17 was released (2002)
- Tech. document on composite certification roadmap (2003)
- Policy on substantiation of secondary structures (2005)
- Policy for bonded joints & structures was released (2005)*
- Composite maintenance training modules (drafted in 2005)

* FAA Technical Center reports exist for detailed background on engineering practices

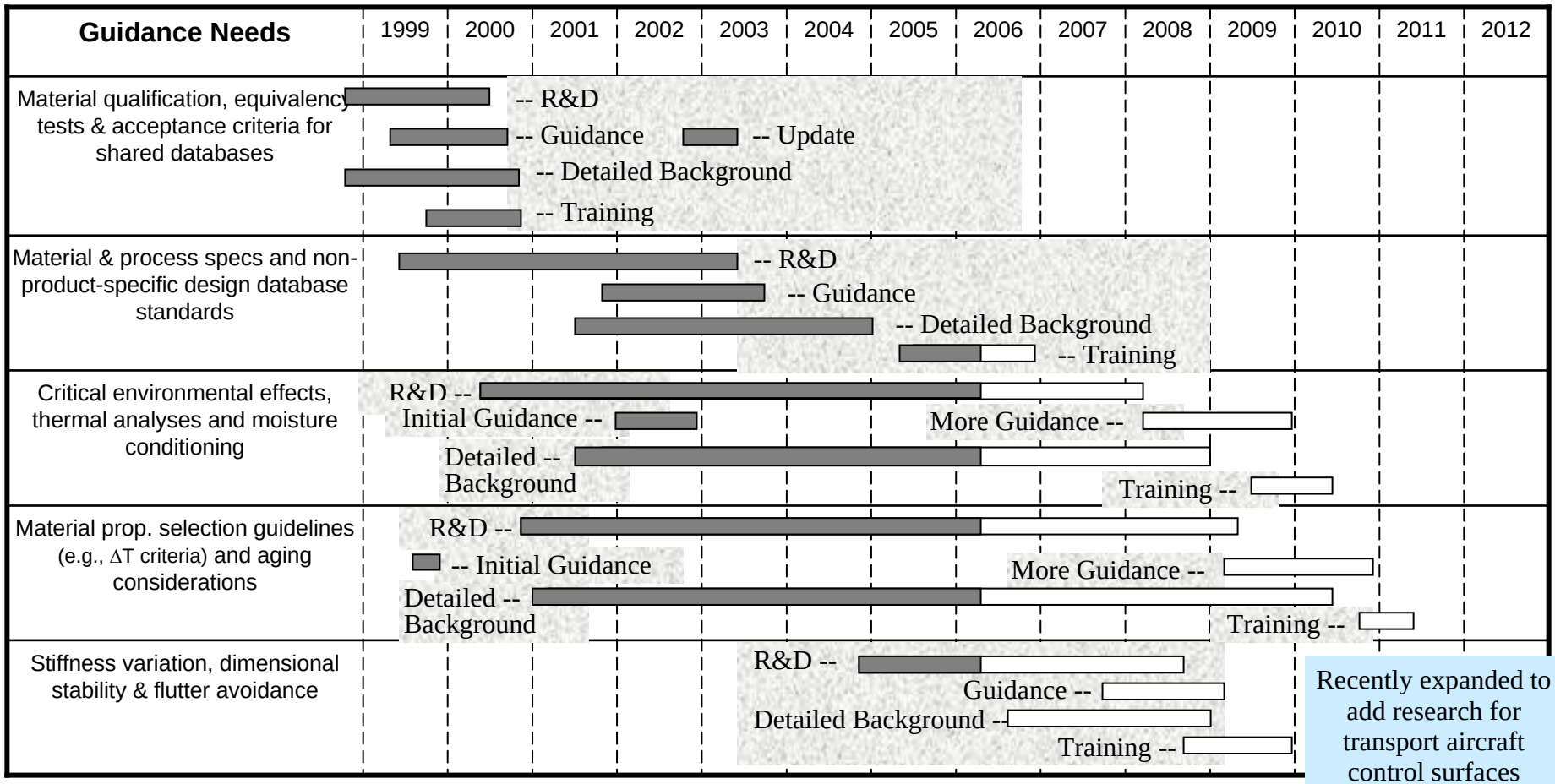
Appendix

The remaining charts contain additional details:

a) Schedules for the composite safety & certification initiatives

b) References for supporting FAA Technical Center Reports

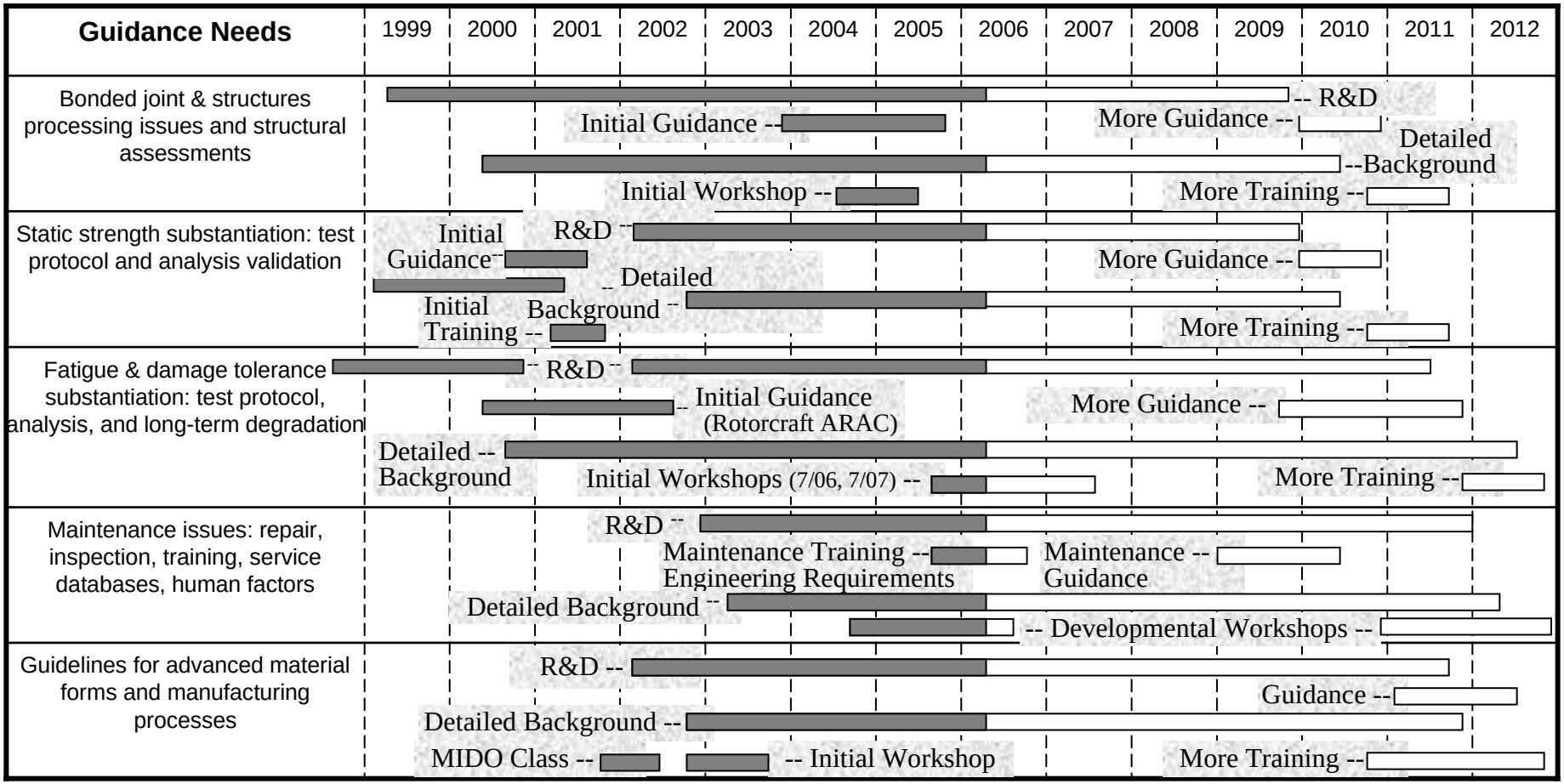
Composite Safety & Certification Initiatives: Databases, M&P Specs, Environmental Effects & Stiffness Assessment



Recently expanded to add research for transport aircraft control surfaces (FAA & NASA effort)

Last updated on March 15, 2006

Composite Safety & Certification Initiatives: Static Strength, Damage Tolerance, Bonded Joints and Advanced Material Forms & Manufacturing Processes



Last updated on March 15, 2006

Detailed Background: FAA Technical Center Reports

Material Standardization and Shared Databases

- "Material Qualification and Equivalency for Polymer Matrix Composite Material Systems," DOT/FAA/AR-00/47, April 2001, "Update Procedure," DOT/FAA/AR-03/19, September 2003.
- "Verification of the Wyoming Combined Load Compression (CLC) Test," DOT/FAA/AR-00/26, August 2000
- "Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Unidirectional Prepregs," DOT/FAA/AR-02/109, March 2002.
- "Guidelines for the Development of Process Specifications, Instructions and Controls for the Fabrication of Fiber Reinforced Polymer Composites, DOT/FAA/AR-02/110, March 2002.
- "Tabbing Guide for Composite Test Specimens," DOT/FAA/AR-02/106, October 2002.
- "A Comparison of CEN and ASTM Test Methods for Composite Materials," DOT/FAA/AR-04/24, June 2004
- "Comparative Testing to Assess Equivalence of CEN and ASTM Test Methods for Composite Materials", DOT/FAA/AR-04/50, February, 2005

Advanced Material Forms and Processes

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Research reports are available at http://actlibrary.tc.faa.gov/

Detailed Background: FAA Technical Center Reports, *cont.*

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